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Title: Landfill Gas Extraction Constant Flow Control Method and Device

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

[0002] Not Applicable.

REFERENCE TO A MICROFICHE APPENDIX

[0003] Not Applicable.

BACKGROUND OF THE INVENTION—FIELD OF THE INVENTION

[0004] This invention relates to a control method and apparatus for optimizing the extraction of decomposition gas from solid waste landfills. More specifically, the present inventions pertains to a method using a wellhead device that when installed and operated on a landfill gas extraction well will provide the capability to select and maintain a constant flow rate of gas extraction from the subsurface. This capability allows controlling the extraction at near the gas generation rate for the well. The device also includes a high temperature shutdown feature in which the wellhead will stop gas extraction from the well for the purposes of minimizing the potential or exasperation of subsurface fires.

BACKGROUND OF THE INVENTION—DESCRIPTION OF RELATED ART

[0005] Once municipal solid waste is disposed of at a landfill, the organic fraction of the waste begins to decompose. This decomposition first proceeds through an aerobic biodegradation process where all the available oxygen in the buried waste is consumed. The decomposition then proceeds through a strictly anaerobic biodegradation process where the principle constituents of landfill gas are formed. Landfill gas consists of approximately 55% methane, 44% carbon dioxide and less than 1% trace gases. The trace gases consist of a wide variety of volatile organic compounds, which vary depending on the particular landfill. Noteworthy is the fact that oxygen is toxic to the microorganisms typically responsible for methane gas generation.

[0006] Since landfill gas is constantly being produced as a result of waste decomposition, landfill gas will move from the buried waste towards the ground surface and will result in surface emissions to the atmosphere. The constant generation of landfill gas also results in a flushing or purging action within the subsurface that results in the removal of air, thus further facilitating the anaerobic biodegradation process.

[0007] Surface emissions of landfill gas is not a desirable condition because the primary constituents of landfill gas are well known green house gases, which are thought to be contributing towards global warming. In addition, the trace gases present in landfill gas are believed to participate in an atmospheric photochemical reaction that leads to the formation of ozone, a principle constituent of smog.

[0008] In addition to surface emissions, landfill gas may also move or migrate laterally in the subsurface away from the buried decomposing waste, and may accumulate in near-by buildings or other structures. This condition creates a potentially dangerous condition due to the methane content of landfill gas. When methane is present in a concentration ranging from approximately 5 to 20 percent by volume it is potentially explosive. Another issue associated with subsurface migration of landfill gas is that it may also come into contact with groundwater and create the potential for groundwater contamination due to the presence of contaminating trace gases.

[0009] Thus it is desirable to collect landfill gas to prevent these negative environmental effects. It is also desirable to collect landfill gas for energy recovery purposes, as the methane content of landfill gas can be relatively easily used as a fuel.

[00010] Active landfill gas well extraction systems are used to control landfill gas surface emissions, control landfill gas subsurface migration away from the landfill, and often to collect landfill gas for energy recovery. These systems typically include an array of both vertical and horizontal landfill gas extraction wells that are in fluid communication with a common header piping system. The header piping system is, in turn, fluidly connected to a vacuum source, typically a centrifugal blower or other similar turbo-machine. Following extraction by the system, the gas may be incinerated by a flare, may be directly used as a fuel, or may be conditioned and then used as a fuel.

[00011] The landfill extraction system wells are either drilled or trenched into the landfill waste column and they consist of both perforated-piping sections and solid-piping sections. The solid piping section is nearest the surface of the landfill. The perforated-piping section is the

deeper piping. The point at which the solid piping changes to perforated piping is a major design consideration for an extraction well, since it significantly influences the maximum allowable suction that can be applied to each well.

[00012] Each extraction well is in fluid communication with a header piping system through a wellhead assembly. The wellhead assembly typically consists of a gate valve used for throttling the volumetric flow rate of landfill gas from the extraction well and a sample collection port. The wellhead may also include a flow rate measurement device.

[00013] An operating goal of the landfill gas well extraction system is to remove gas at the approximate rate of its generation. The rational for this goal is the consequence of over- or under- extraction rates. Under-extraction rates mean the extraction rate is not high enough to prevent gas from reaching the surface or prevent subsurface migration. This results in air pollution, or a fire hazard. Over-extraction rates mean the extraction rate is high enough to draw large amounts of air into the waste column. This may cause a subsurface fire, and will kill many of the microorganisms responsible for the formation of methane, resulting in reduced methane recovery. Consequently, the gas flow rate from each individual extraction well, or group of adjacent wells, needs to be carefully monitored and controlled within a narrow operating range to prevent over- or under- extraction of landfill gas.

[00014] Several factors are involved in causing short-term over- or under- extraction rates in present extraction systems. Extraction systems typically rely upon one common vacuum source that is in fluid communication with the header piping system for all the wells. A centrifugal blower or similar turbo-machine is most commonly used as a vacuum source, although reciprocating compressors have also been used. The efficiency of turbo-machines is affected by gas temperature, which results in a variation in the mass flow rate developed by the turbo-machine with changes in temperature. This temperature-caused flow variation is reflected in a variation of the extraction rate at each of the system wells. The gas temperature changes with ambient temperature that, in turn varies over the course of a day, resulting in a diurnal variation. Landfill gas is alternately diluted and concentrated as a result of this mass flow rate variation. The magnitude of the effect depends upon the magnitude of the mass flow variation of the turbo-machine and the individual well construction characteristics.

[00015] Changing barometric pressures is another factor affecting extraction rates. Variations in atmospheric pressure modify the over-all resistance to flow in the extraction well and header piping system.

[00016] Changes in the landfill surface topology, such as differential settlement of the landfill surface, the development of landfill surface cracks, or waste separation from side slopes of the landfill may change the flow characteristics of the extraction system. These may cause a lower resistance to flow than an intact surface resulting in a short-circuit flow of air into the extraction system resulting in large quantities of air being drawn into the subsurface.

[00017] All of these effects result in a continuous cycle of over and under extraction of landfill gas by the extraction system. Methods to control these cycles have been proposed. U.S. Patent 4,026,355 (Johnson et al.) describes a control method using various measurements of pressure within the landfill. This method has the drawback of requiring precise subterranean pressure measurements in the landfill that involve remote data communication. Such remote measurements in a landfill environment are subject to a variety of malfunctions from natural and man-made causes. U.S. Patent 4,890,672 (Hall) describes a control method using measurement of the extracted gas temperature. This method is based on correcting an over-extraction by measuring its consequences, rather than controlling to prevent over-extraction. U.S. Patent 6,169,962 (Brookshire et al.) describes a complex and extensive computer-controlled system and computer program involving using a wide variety of parameters to determine the control signal for the control valves in the extraction system. This system requires an expensive instrumentation and control system, and the communications for a remote control computer, which again is subject to malfunctions in a landfill environment.

[00018] What is needed is a simple, rugged, inexpensive control method and system that is based on the causes of landfill gas extraction system over- or under- extraction rates.

SUMMARY OF THE INVENTION

Objects and Advantages

[00019] One object of this invention is to provide a landfill gas extraction control method and apparatus that will control short-term fluctuations in extraction flow that can lead to over- or under- extraction of gas.

[00020] A second object of this invention is to provide a landfill gas extraction control method and apparatus that requires minimal supervision.

[00021] A third object of this invention is to provide a landfill gas extraction control method and apparatus that is low in installation and maintenance cost.

[00022] A fourth object of this invention is to provide a landfill gas extraction control method and apparatus that will provide a shutdown of the gas extraction if dangerously high extraction temperatures occur.

Brief Description of the Several Views of the Drawings

[00023] A more complete understanding of the invention can be obtained by considering the detailed description in conjunction with the accompanying drawings, in which:

[00024] Figure 1 is a graph of the relationship of the area of a typical landfill gas flow restriction and the differential pressure across the flow restriction at a constant flow rate.

[00025] Figure 2 shows curves of the differential pressure regulating valve differential pressure versus differential area for flow rates of 5 to 50 scfm.

[00026] Figure 3 shows the arrangement of the methane gas extraction constant flow wellhead.

[00027] Figure 4 is a schematic of the differential pressure-regulating valve.

[00028] Figure 5A is an isometric view of the methane gas extraction constant flow wellhead.

[00029] Figure 5B shows the control circuit inputs and outputs.

Reference Numerals in Drawings

These reference numbers are used in the drawings to refer to areas or features of the methane gas extraction constant flow wellhead.

50. Manual Flow Regulating and Shut-off Valve
52. Differential Pressure-Regulating Valve
54. Upstream Pressure Tap
55. Intermediate Pressure Tap
56. Downstream Pressure Tap
58. Temperature Sensor
60. Sample Collection Port
62. Control Section Housing
64. Control Circuit
66. Data Port
70. Differential Pressure Regulating Valve Flow Area

72 Differential Pressure Regulating Valve Flap
74. Differential Pressure Adjustment Valve Stem
76 Differential Pressure Regulating Valve Stepper Motor
78. Differential Pressure Regulating Valve Flap Position Sensor
80. Differential Pressure Regulating Valve Body and Bonnet
82. Wellhead Piping

DETAILED DESCRIPTION OF THE INVENTION

Preferred Embodiment

[00030] The principle of operation of the present invention is based on well-known fluid dynamic considerations. The first law of thermodynamics general energy equation can be used to relate the pressure loss resulting from fluid flow within a piping system to a specific flow rate. In flow rate measurement a restriction within a pipe is constructed which reduces the cross-sectional area of the pipe's traverse plane with respect to fluid flow. The pressure difference measured at the upstream and down streamside of the restriction, known as differential pressure, is used to determine the flow rate of the fluid. The unique flow rate is also dependant upon the cross sectional area of the restriction, the geometry of the piping system up and downstream of the restriction, as well as the fluid characteristics.

[00031] In a situation where the flow rate, gas characteristics, and pipe geometry are held constant, an inter-relationship will exist between cross sectional area of the restriction and the pressure difference across the restriction. A range of paired values of these parameters is possible in which the flow rate is constant, as illustrated by figure 1, which uses a flow rate of 20 scfm. This principle is exploited in the present invention through using it as a basis for a highly effective throttling valve, known as the differential pressure-regulating valve. Throttling is the positioning of the valve to provide a particular flow restriction.

[00032] There is a range of differential pressures that approximate a linear relationship with the flow area for a given constant flow rate. Figure 1 shows this linearity approximation in the range 1 to 4 inches water column (WC). Lower differential pressures than this are non-linear, requiring larger and larger changes in flow area for a given change in differential pressure. Conversely at higher differential pressures the change in differential pressure becomes larger for a given change in flow area such that control becomes very difficult. In this linear range, maintaining a constant flow rate involves changing the flow area a given amount for a given change in differential pressure. Since the required change in flow area varies over the linear

range, the differential pressure-regulating valve internals provide increased changes in flow area as the valve is opened.

[00033] The flow control section of the wellhead assembly is designed to maintain a constant gas flow by varying the available cross sectional area of the differential pressure-regulating valve so gas flow will respond to changes in fluid conditions external to the wellhead. These changes manifest themselves as changes in the differential pressure across the complete wellhead assembly gas path.

[00034] The complete wellhead assembly includes the flow control components as shown in figures 3 and 5A, and consists of a manual flow regulating and shut-off valve (50), an automatically adjusting differential pressure-regulating valve (52), arranged in series in the flow path from a well, and pressure sensing taps (54, 55, 56). The flow is controlled at the desired flow rate through action of the differential pressure-regulating valve, which throttles the gas flow to achieve a constant differential pressure across the complete wellhead assembly. The differential pressure across the complete wellhead assembly is the difference in pressure measurements between the inlet to the differential pressure-regulating valve and the outlet of manual flow regulating and shut-off valve as measured at the upstream pressure tap (54) and the downstream pressure tap (56). This differential pressure is used as the operating control parameter for the pressure-regulating valve. Maintaining the differential pressure across the complete wellhead assembly at the desired operating control point assures a constant flow rate.

[00035] The differential pressure-regulating valve (52) maintains the constant flow rate through movement of the differential pressure-regulating valve flap (72) to vary the throttling of the gas flow. The manual flow regulating and shut-off valve (50) is adjusted when the wellhead is placed in service to maintain the differential pressure in the range of 1 to 4 inches water column (WC) across the differential pressure-regulating valve, as measured between the upstream pressure tap (54) and the intermediate pressure tap (55). This adjustment of the manual valve to set the differential pressure across the differential pressure-regulating valve range optimizes the throttling capability of the differential pressure-regulating valve.

[00036] The minimum requirements for a wellhead consists of a section of piping with a valve, used for manual flow regulation and shut-off (50), and a tap with a shut-off valve for obtaining gas samples (60). The present invention adds to this an automatically controlled differential pressure-regulating valve (52); three pressure sensing taps, the upstream pressure tap

(54), on the gas well side of the pressure-regulating valve, the intermediate pressure tap (55) between the pressure-regulating valve and the manual flow regulating and shut-off valve, and the downstream pressure tap (56), located downstream of the manual valve (50); a temperature sensor (60) upstream of the differential pressure regulating valve; a control circuit (64); and a data port (66).

[00037] In figure 3 the arrow labeled "From Well" depicts the flow from the landfill to the wellhead assembly, and is also called the upstream direction. The arrow labeled "To Vacuum Source" depicts the flow from the wellhead assembly, and is also called the downstream direction.

[00038] The valve used for manual flow adjustment and shut-off (50) is used by the constant flow control wellhead to establish an initial desired differential pressure across the differential pressure regulating valve by throttling the vacuum applied to the wellhead differential pressure-regulating valve. This valve is in a fixed position during normal operation, and is used only during periodic flow adjustments.

[00039] The differential pressure-regulating valve (52), shown in more detail in figure 4, is a gate valve with a geometrically pre-determined valve opening area that provides a linear change in differential pressure with a change in valve flap position. The term linear is used to describe a change that approximates a straight line when the effect of variations in one parameter (example area) is graphed against a second parameter (example differential pressure). The flow area (70) portion of the valve is shaped as shown in figure 4. The valve flap moves in a channel integrally cast in the valve body (80). The differential pressure-regulating valve is designed to initiate operation with a differential pressure of 2.0 inches WC, and each position of the valve flap will represent a unique flow rate, from fully open, which opens the entire flow area to flow, to nearly closed, which allows flow only through the narrowest bottom portion of the flow area. The flow area (70) optimizes the flow control as the shape of the opening was calculated to provide a linear response between a change in valve flap position and the resulting change in differential pressure.

[00040] The shape of the differential pressure-regulating valve flap area is derived through manipulation of the orifice flow meter equation, which is derived from the Bernoulli and Continuity Equations. The orifice flow meter equation is as follows:

$$Q = KA_{\circ}\sqrt{\frac{2g\left(\gamma_m - \gamma_{lfg}\right)\Delta h_m}{\gamma_{lfg}}}$$

Where:

Q = Flow Rate
A = Cross Sectional Area of Orifice
K = Discharge Coefficient
g = gravitational acceleration constant
γ = specific weight
Δh = differential pressure, measured as head
m subscript denotes manometer fluid characteristics.
lfg subscript denotes landfill gas characteristics

[00041] When the orifice flow meter equation is re-arranged and the flow rate is held constant and other parameters are specified, a relationship between the cross sectional area of the orifice and the differential pressure (DP) measured across the orifice can be defined. This relationship defines a range of pair values of cross sectional area and DP that are possible for the given flow rate. This relationship is as follows:

$$A_{\circ} = \frac{Q}{K\sqrt{\frac{2g\left(\gamma_m - \gamma_{lfg}\right)\Delta h_m}{\gamma_{lfg}}}}$$

This equation is plotted in Figure 1 for the flow rate of 20 standard cubic feet per minute (scfm).

[00042] The Discharge Coefficient, K, is a function of approach geometry and the Reynolds Number (a measure of flow characteristic). In designing the valve flow area, an assumed discharge coefficient was initially used. The initial design of the flow area was constructed and subsequently tested. A discharge coefficient was determined through specific calibration testing of the initial flap opening design. The fluid dynamic testing of the flow area revealed that the discharge coefficient changed as the flap was raised in elevation. This information was used in developing the final design of the flow area.

[00043] Considering the magnitude of pressures that are typically encountered in landfill gas extraction wells, the units of pressure measurement that was selected for Δh_m is inches water column (WC), which is pressure expressed as head. The manometer fluid is therefore water and

the characteristics of water at standard conditions for measurement were utilized in the equations presented above.

[00044] The specific weight of landfill gas, γ, was estimated by determining the weighted average of methane, carbon dioxide and nitrogen specific weights. Each constituent of landfill gas was weighted by the concentration it typically has in extracted landfill gas.

[00045] The procedure for calculating the flap opening geometry proceeded in a step-wise fashion. One set of calculations was performed for each selected flow rate. The selected flow rates ranged from 1 to 50 scfm. Once a flow rate was selected, the calculations proceeded with determining the cross sectional areas required for differential pressures (DP) in the range of 0 to 4.0 inches WC for the selected flow rate. This results in a curve of values similar to the value seen in Figure 1. The range of DP between 1 and 4.0 has a strong linear relationship with the change in required cross sectional area of the flap opening. Also, this range of DP values produces the greatest change in cross sectional area for a given change in DP.

[00046] A rectangular opening was designed for the flow rates ranging from 0 to 5 scfm to provide the required cross sectional area. The width of the flap opening was increased with height for flow rates above 5 scfm to provide the required cross sectional area for the given flow. The flap opening width for each given flow rate was determined by reiteratively selecting a width until a width was found that could yield a "workable" flap elevation change per 0.1 inch WC DP change.

[00047] The stepper motor (76), shown in figures 3, 4, and 5A, controls the differential pressure regulating valve flap position. The stepper motor, as shown in figure 4, is connected to and rotates a valve stem (74). The stem has male threads along its length on the end in contact with the valve flap (72), and the threads mate with female threads in the valve flap opening that receives the valve stem. The flap is constrained from rotation by the valve body channel in which it is located, so rotation of the stem causes the flap to move up or down depending on the direction of the stem rotation. An alternative valve configuration may use a stem that moves up and down with the valve flap in response to rotation of a nut connected to the stepper motor. An integral valve flap position sensor (78) is incorporated in the valve. The valve body and bonnet (80) is cast in two pieces with the restricted flow area (70) cast integral with each half. Each half has a valve flap channel on the mating side in which the valve flap can move up and down. The

two halves are assembled together with the valve flap and then the body assembly is attached to the control section of piping (82).

[00048] The piping adjacent to the automatically controlled differential pressure adjustment valve (82), as shown in figures 3 and 5A, contains a pressure sensing tap (54) upstream of the valve, a second pressure sensing tap (55) downstream of the valve, and a third pressure sensing tap downstream of the manual flow regulating and shut-off valve (56). Sensors in the control circuit (64), with inputs and outputs shown in figure 5B, measure these pressures and the difference in pressure is calculated from these measurements to yield the differential pressure across the differential pressure-regulating valve and the differential pressure across the complete wellhead assembly. These differential pressures may be displayed using the data port in the control circuit. There also is a temperature sensor (58) upstream of the valve. This signal is also transmitted to the control circuit. Another tap is used as a sample collection port (60).

[00049] The control circuit (64) is battery powered in the preferred embodiment, but may be powered from external sources. The circuit drives the regulating valve stepper motor (76) based on any measured deviation from the differential pressure setpoint, which is the differential pressure across the complete wellhead assembly after the desired flow rate has been established. The control algorithm for this is simple as the regulating valve flow area (70), shown in figure 4, is shaped to provide a linear, or constant, change in differential pressure for a given valve flap movement over the entire range of valve travel. This linear relationship is shown for the preferred differential pressure range of 1.5 to 2.5 inch WC in figure 2. The control circuit is normally in a dormant state and approximately every 10 minutes will go to an active state where the differential pressure value is sampled and processed by averaging the values over time to account for fluctuations in the measurements, and to allow rounding the average. If needed, the control then produces increments of valve movement proportional to any deviation of the average differential pressure from the differential pressure setpoint, and then it returns to the dormant state.

[00050] The upstream gas temperature sensor (58), that provides a temperature input to the control circuit, is used with clock time to provide a data set of time and temperature. If the temperature exceeds the operator-selected shutdown setpoint value the control circuit will close the regulating valve.

[00051] Federal regulations (40 CFR 755 and 756) require monthly measurement of the temperature of the landfill gas and the gauge pressure at each well. Figures 5A and 5B show the data port (66) on the control circuit that provides the display capability, using a portable hand-held computing device such as a personal digital assistant (PDA). The control circuit provides the temperature and pressure data handling through the data port. The portable hand-held computing device is used to adjust the differential pressure setpoint that the control circuit uses for positioning the regulating valve, and the temperature setpoint used to shutdown the well. The control circuit also provides information on battery status and the status of the control circuit, its sensors, and the stepper motor. It also may provide power to warning devices in the event of such conditions as low battery voltage or high gas temperature.

Additional Embodiments

[00052] The pressure-regulating valve position in the flow path may be varied if needed to accommodate existing installation configurations. The manual valve may be placed in the flow path upstream of the pressure-regulating valve. In this case, the pressure taps will be placed upstream of the manual valve, between the manual valve and the pressure-regulating valve, and downstream of the pressure-regulating valve.

Operation

[00053] This method of landfill gas extraction control using the constant flow wellhead has four operating modes: normal operation, data acquisition to meet well monitoring requirements, flow adjustment to compensate for longer term changes in gas extraction rate, and periodic calibration of the instrumentation.

[00054] Startup following installation of the constant flow control wellhead requires checking for closure of the manual flow regulating and shut-off valve, establishing battery power to the wellhead, and then disabling the control circuit differential pressure monitoring using a personal digital assistant (PDA) attached to the data port. The differential pressure-regulating valve is then positioned at a nominal position established by experience with the optimal flow rate from the well. The manual flow regulating and shut-off valve is then opened to establish flow from the well as the real-time differential pressure reading is monitored on the PDA. The manual flow

regulating and shut-off valve is then set to a position to establish a differential pressure near the desired value of 2 inches WC across the differential pressure-regulating valve.

[00055] Once the 2-inch WC differential pressure is established across the differential pressure-regulating valve, the differential pressure across the complete wellhead assembly is measured and this measured value is entered into the control circuit as the control setpoint using the PDA.

[00056] The control circuit is then placed in the normal operation mode. Normal operation is to maintain a constant flow rate from the well by monitoring and maintaining the differential pressure across the complete wellhead assembly. Periodically the control circuit will activate to monitor and process the differential pressure measurements and adjust the regulating valve flap height as needed to maintain a constant differential pressure.

[00057] Monthly, or more frequently if desired, the extraction well will be manually monitored. Monitoring is required by federal regulation (40 CFR 756) to include collection of a sample of landfill gas using the sample port on the wellhead. A PDA is connected to the data port and used to place the control circuit in the data acquisition mode. In this mode the gas temperature and gage pressure is measured as well as regulating valve flap position. The well flow rate is derived from the differential pressure across the entire wellhead assembly by a conversion provided in the PDA software. The PDA is used to transfer this data and the well identification to a permanent record.

[00058] The gas sample is analyzed to determine its composition and the results used to determine if the composition indicates the present flow rate from the well is resulting in over or under extraction. If a change in flow rate is indicated by the gas analysis results, the flow rate from the well is adjusted.

[00059] The flow rate of the wellhead assembly is changed using the PDA to place the control circuit in the flow adjustment mode. This suspends the monitoring and differential pressure maintenance of the normal operating mode and permits commands from the PDA to position the regulating valve flap. The regulating valve flap location is then adjusted open if the well is under-extracted, or closed if the well is over-extracted. The PDA display shows the changes in differential pressure across the differential pressure-regulating valve as this valve is adjusted.

[00060] Following adjustment of the regulating valve flap elevation, the desired differential pressure across the regulating valve of approximately 2 inches WC is re-established by adjusting

the manual flow regulating and shut-off valve. Once the desired differential pressure is attained across the regulating valve, the differential pressure across the complete wellhead assembly is measured and entered as the new control set point. At this point, the flow adjustment mode is suspended and the monitoring mode is re-established.

[00061] Periodically the pressure sensors will require a calibration check. The control circuit is placed in calibration mode using the PDA. This suspends the monitoring and differential pressure maintenance of the normal operating mode and permits attachment of a transfer pressure standard to the pressure taps. The data from the standard is compared to the control circuit readings at various regulating valve flap positions to determine the need for adjustment of the control circuit.